WHAT HAVE WE LEARNED ABOUT COMPUTER BASED INSTRUCTION IN MILITARY TRAINING?

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A number of papers prepared for NATO Research Study Group (RSG) 16, "Advanced Technologies Applied to Training Design," concern the direct, interactive use of computers in military training. For convenience, all these applications—which include drill and practice, tutorial dialogue, intelligent tutoring systems, tutorial simulations, interactive multimedia instruction, and similar approaches using computers to adjust instructional presentations to the needs of individual learners—may be called computer based instruction (CBI). Over a ten-year (1985–1995) period RSG 16 heard many papers of which about 31 concerned CBI. These papers were prepared for RSG 16 by 41 scientists in 8 different NATO countries. They presented valuable data and significant insights concerning the design, development, use, and evaluation of CBI in military applications. They introduced issues, some of which they answered and many of which remain unsettled. These issues and answers are summarized in this paper.

NEED FOR CBI

The challenges to successful training for military personnel have only increased since they were articulated by Wiggs and Seidel (1987). Workplaces in all sectors have become increasingly infused with technology, requiring workers to become increasingly "technology literate." The complexity of military operations has continued to increase along with the human performance needed to operate, maintain, and deploy the materiel, devices, and equipment they employ. At the same time, limitations in time, funding, training devices, training personnel, ranges, supplies, and other resources such as ammunition and fuel have made training missions increasingly difficult to accomplish.

Fortunately, technology may also provide a solution to these problems. It is being pursued in both civilian and military sectors as the key to meeting the challenges it, at least in part, has brought about. Military trainers, among others, are pursuing the use of

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computers in instruction because they must. In peacetime, they are unlikely to receive more resources than they have now to establish and maintain personnel readiness. Instead they must become increasingly efficient in obtaining value from resources at hand. CBI promises to provide a significant portion of this efficiency. Based on the evidence presented to RSG 16 and other forums, it can deliver on its promise.

INDIVIDUALIZATION

Research by Bloom (1984) suggests that the difference between those taught in classroom groups of 30 and those taught one-on-one by an individual instructor may be as great as two standard deviations in achievement. Unfortunately, individual tutoring is prohibitively expensive. In military training as in civilian education, the provision of a single instructor for every student is an economic impossibility. Yet the instructional efficiency that can be accomplished by tailoring instructional sequence, content, pace, and style to the needs of each learner is becoming an economic necessity in military training for the reasons discussed above. Computers in military training may replace some of the individualization lost to the economic necessities of group instruction. The approach is a classic economic solution in that it substitutes the capital of CBI for the labor of human instructors.

Several RSG 16 authors including Wiggs and Seidel (1987), Yasutake (1987), and Samarapungavan et al. (1991) stressed the need to develop an organized body of principles for individualizing instruction. Direct attempts to develop these principles have been pursued using two different approaches to development: artificial intelligence using principles of knowledge representation and optimization of instruction using optimal control theory.

Applications of artificial intelligence in CBI have involved direct attempts to imbue computer (or instructional computer software) with the capabilities possessed by a human tutor. These capabilities are usually said to be (a) subject matter knowledge, which among other things roughly represents the goal state for the learner, (b) knowledge of the student, which represents the current state of the student's knowledge and those characteristics of the student (e.g., ability, learning style, relevant background) that are required for tailoring instruction to meet his or her needs, and (c) tutorial knowledge, which the system can use to create an environment in which the student will progress from the current state to the goal state. Functionally, these applications may be characterized by an ability (a) to generate instructional presentations in real time in response to learner needs and (b) to allow mixed initiative instruction in which learners may freely interrogate the tutor, just as the tutor interrogates students in standard CBI.

Almost half of the CBI articles presented to RSG 16 concerned these knowledge-based approaches. Development of at least seven specific systems were discussed. These discussions are thoughtful and stimulating, but aside from student-computer interactions presented by Feurzeig (1987), no effectiveness or cost data were presented for these systems. This is characteristic of the field, which has been slow to produce data. It is notable that in addition to generating a level of individualization that would be unattainable without computer intelligence—or the presence of a human tutor—a second primary motive for developing these systems was to reduce the costs of instructional materials preparation—automation was sought to reduce these costs.

Four issues concerning these applications arise frequently and seem especially worthy of note:

- Role of instructors and formal instruction. If all military personnel can carry a "Ph.D in the pocket," that provides both job aiding and training anywhere, at any time, what is the role of formal schooling? What is the role of military instructors? How much training is really necessary if an expert advisor is always at hand—or in pocket? These issues were raised by many of the RSG 16 commentators. Answers were speculative.
- Overlay and misconceptions. On a more technical level, many RSG 16 commentators discussed overlay techniques for modeling student knowledge. What the student does to solve a problem is overlaid onto an expert's solution, and the mismatches are assumed to indicate what the student has yet to learn. Other commentators discussed student misconceptions. Wrong approaches are not assumed to be drawn at random, but to rise from at least partially well-constructed notions of the problem state. Overlays will not identify misconceptions. There is a widespread assumption that misconceptions must be directly addressed in an effective intelligent tutor. Is this true? Are time and resources better spent identifying misconceptions or simply presenting and re-presenting problems and their solution by experts? This is an issue that could easily be addressed by empirical study.
- Individual tutoring. Most research on instruction concerns group learning. Intelligent tutoring systems address a very different setting for instruction in which a single instructor attends to the needs of a single student. Far less is known about effective approaches for this setting, because it has received far less research attention. Again, this is an issue that could readily be addressed by empirical study.
- Coaching. Coaching generally concerns two issues: what to say and when to say it. A model of expertise may not communicate well to a learner whose understanding of the subject matter falls short of expertise. A computer coach must be able to articulate tutorial feedback and help to learners in terms they can understand. Secondly the timing of tutorial commentary is discussed by many authors. When should the progress of a learner be interrupted to provide feedback? Both of these issues have received more discussion than systematic research attention.

Applications of control theory were discussed by Marguin (1987) and von Baeyer (1991). In these applications the development of knowledge representations for instruction is finessed by taking a more behaviorist approach to instruction. Individualization is achieved by generating parameter values for student ability, item difficulty, and their interactions. For instance, the following transition matrix might be used in a three-stage theory of learning and forgetting in which items to be learned by student pass from an unlearned to a learned state:

Matrix A

State on Trial n	State on Trial n+1: L	S	U
L	1	0	0
S	c	1-c	0
U	a	b	1-a-b

Matrix B

State on Trial n	State on Trial n+1: L	S	U
L	1	0	0
S	0	1-f	f
U	0	0	1

This model describes the probabilities of transitions between unlearned (U), short term (S), and learned (L) states for learning (Matrix A) and for forgetting (Matrix B) of a specific item by a specific learner. Estimates of the parameters (a, b, c, f) can be used to choose items to present to a learner that can be proven by formal means to maximize achievement subject to such constraints as the amount of learning time available, number of items in the full set, and the parameters themselves.

EFFECTIVENESS

Student achievement using CBI is of natural interest, and five RSG 16 papers report data on the effectiveness of CBI. Dana (1987) reported reductions from 40% to 10% in washback rates, earlier screening of student suitability for training, and 1–2 week reductions in training time. Yasutake (1987) reported 24% to 35% time savings for four courses, positive (80–90%) student attitudes, and negative instructor attitudes for computer managed instruction. Noja (1987) reported reductions in training time from 8 to 5 weeks, equivalent student achievement for electronic theory and improved student achievement for electronic applications. In comparing results from a computerized, hand-held training aid with text-based workbooks, Wisher (1987) reported more course completions (91% as contrasted with 58%) and better test performance by a ratio of 2:1 for the computerized training aid. Noja (1991) reported 30% to 50% reductions in training time and per student per year savings of $5,500 for CBI.

Many studies comparing CBI with more conventional approaches have been reported in the literature. Meta-analysis is widely used in both education and medical research to combine, quantitatively, the results from many studies into a single metric, called effect size, for the overall effectiveness of some treatment or approach. Effect size is a standard score that measures standard deviations of difference between two means—one of which, for instance, might be derived from the performance of a group using instructional technology and the other of which might be derived from a group acting as an experimental control. It is calculated by dividing the difference of the two means by an estimate of the standard deviation of their combined distributions. In the cases discussed here, the larger the effect size, the stronger the case for using CBI.

Because standard deviations lack intuitive appeal as measures of population differences, effect sizes may be roughly interpreted as measures of the extent to which the performance of 50th percentile students may be raised or lowered by the experimental treatment or approach. For instance, an effect size of 0.50 obtained for some instructional

Table 1. Some effect sizes for CBI

Where	Effect size	No. of studies	50%tile to %tile
Elementary school[a]	0.47	28	68%tile
Secondary school[b]	0.42	42	66%tile
Higher education[c]	0.26	101	60%tile
Adult education[d]	0.42	24	66%tile
Military training[e]	0.40	38	66%tile
Overall	0.39	233	65%tile

[a] (Kulik, C-L Kulik, and Bangert-Drowns, 1985)
[b] (Bangert-Drowns, C-L Kulik, and Kulik, 1985)
[c] (C-L Kulik and Kulik, 1986)
[d] (Kulik, C-L Kulik, and Shwalb, 1986)
[e] (Johnston and Fletcher, 1995)

Table 2. Some effect sizes for interactive videodisc instruction[a]

Where	Effect size	No. of studies	50%tile to %tile
Military training	0.39	24	65%tile
Industrial training	0.51	9	70%tile
Higher education	0.69	14	75%tile
Overall	0.50	47	69%tile

[a](Fletcher, 1990)

approach might be interpreted as roughly equivalent to raising the achievement of 50th percentile students to that of 69% percentile students. Some effect sizes for CBI are shown in Table 1. As the table shows, effect size calculated across 38 studies of CBI applied in military training was 0.40, suggesting a raise in student performance from the 50th percentile to the 66th percentile.

Table 2 shows effect sizes for computer-controlled interactive videodisc instruction compared to conventional instructional approaches in three different settings: higher education, industrial training, and military training. As the table shows, the effect size for military training calculated for CBI with added multimedia capabilities was .39, suggesting an improvement in student performance from the 50th percentile to the 65th percentile. This is about the same as the effect size reported for CBI in military training. By contrast the effect size reported for CBI in higher education was 0.24 which can be compared with an effect size of 0.69 obtained for interactive videodisc instruction in higher education. Evidently there is more to be learned about the use and effectiveness of multimedia materials in instruction.

It is interesting to note that increased interactivity seems to buy increased student achievement. Among the interactive videodisc comparisons were three that compared branched approaches with linear approaches using the videodisc presentations. Their effect sizes were 0.85, 0.59, and 1.54, suggesting that branching and the individualization it accomplishes contributes to instructional achievement.

TIME TO TRAIN

Most of the effectiveness results presented by RSG 16 authors and summarized briefly above involve savings in time to train. Instructional time savings of about 30% for CBI is a stable and frequent result. It has been reported in independent reviews covering hundreds of evaluation studies by Orlansky and String (1977), Fletcher (1990), Kulik (1994), and Johnston and Fletcher (1995) as well as in specific assessments by Noja (1987), Yasutake (1987), and Noja (1991) writing specifically for RSG 16.

These results suggest significant savings in training costs through the use of CBI. However, in military applications the greatest savings that result from shortened training time may come from reductions in force structure that are possible when people are in training less and available for operational duty longer. Even though they result from reductions in training time, these force structure savings may dwarf those obtained from training. At present and despite its promise, CBI is only used in about 1% of the courses presented by the US military. A comprehensive analysis of personnel cost savings might motivate military planners who are responsible for personnel readiness to significantly increase their investment in CBI.

COSTS

A number of studies compared the costs of CBI with the costs of the instructional approaches it might replace. The costs of different instructional approaches have been assessed by calculating the ratio of the costs of instruction using technology to the costs of instruction using more conventional approaches. In these cases, the lower the ratio, the less costly, relatively, is the approach using CBI. Four classes of costs have been used in comparisons of this sort: research and development costs, initial investment costs, operating and support costs, and salvage costs. Of these four cost ratios are available for studies comparing initial investment costs and operating and support costs. A review of cost studies in military training reported that the ratio (CBI over conventional approaches) averages 0.43 for initial investment and averages 0.16 for operating and support.

Much of the savings realized in these studies of CBI costs arose from the use of simulation to present two-dimensional representations on computer display screens of (three-dimensional) devices that students were to learn to operate and/or maintain. Favorable cost ratios can be obtained when desk-top devices such as personal computers can be substituted in training for actual equipment costing 1–3 orders of magnitude more without sacrificing instructional achievement. These approaches provide only the fidelity that is necessary to achieve given training objectives. Several RSG 16 presenters discussed selective fidelity of this sort. The progression from discussions of high versus low fidelity to those concerning fidelity selected to meet specific training needs is notable in both RSG 16 and in military training circles in general.

COST-EFFECTIVENESS

The central question for decision makers may be that of cost-effectiveness. They may wish to compare the costs to accomplish a given level of achievement using a variety of instructional approaches—and most probably choose the least expensive approach while holding achievement constant. One comparison of this sort using empirically collected data appears to be available (Fletcher, Hawley, and Piele, 1990). It compared the costs to increase comprehensive mathematics scores (computation, concepts, and word problem solving) one standard deviation by using tutors, reducing class size, increasing instructional time, or providing computer based instruction.

The study found great differences in costs among the different approaches. The most cost-effective approaches were found to be computer based instruction or peer tutoring. It is notable that these approaches are not incompatible and that a very strong cost-effectiveness argument might be made for peer tutoring combined with computer based instruction, probably by presenting instruction to more than one student at a time on a single computer station. Studies of this sort have yet to be done for military applications of CBI.

Recommendations for cost-effectiveness analyses in military training have appeared frequently during the last 5–10 years. Orlansky (1992) summarized them as: (1) Include trade-offs between costs and effectiveness in cost-effectiveness evaluations; (2) Include factors of learning and forgetting in cost-effectiveness evaluations; (3) Develop databases on costs, effectiveness, and cost-effectiveness of training systems; and (4) Give high priority to investigations of military effectiveness. These recommendations seem valid and deserving of attention.

ENGINEERING OF TRAINING SYSTEMS

Training objectives usually represent a variety of training outcomes. These outcomes may include speed of response, accuracy of response, retention of either speed or accuracy, transfer of facts, procedures, or concepts to new devices or situations, motivation to continue learning about the subject matter, insight into the subject matter so that the learner can become the teacher, and so forth. To some extent these outcomes must compete for the scarce resources that are made available to implement the training system. Despite this range of intended outcomes, little has been done to develop information on ways to design training systems to accomplish specific outcomes and how to allocate training resources to resolve competition among outcomes. How, for instance, do we design a training system so that retention of accuracy of response is optimized subject to the constraints imposed by available training time and funding resources? Before the advent of computer technology and CBI, the design precision required for this sort of engineering of training systems was impracticable. Now, however, CBI has put it well within out technological reach. An engineering of instruction to obtain predictable, quantitatively specified outcomes is within our reach. We should pursue it.

ACCESS TO CBI MATERIAL, TECHNIQUES, AND DATA

One way for NATO allies to leverage their development of CBI is to develop ways to share CBI materials, techniques, and cost and effectiveness data on results. In an electronic age such sharing of resources usually implies creation and use of databases. Databases on CBI materials, techniques, and results shared among NATO countries would enhance the exchange of information on CBI, stimulate research, and motivate the implementation of this promising technology in military training systems. The need for such a database has been discussed in at least five papers prepared for RSG 16. Several ways for NATO members to access training information of this sort were discussed including agreements to provide direct access to NATO member country databases, development of a NATO gateway to the databases, development of a separate NATO training database, and development of a NATO directory of databases. Fletcher, Alluisi, and Chatelier (1991) suggest that development of a NATO directory of databases may be the preferred alternative. Such a directory would prove of value to researchers, training developers, system program managers, manpower planners, and policy makers concerned with training. The technical issues involved in creation of the directly are strictly routine. However, as Seidel and Chatelier (1991) pointed out, the issues involved in establishing resource sharing agreements among NATO countries are more difficult. Given the leverage and value to be obtained from such a directory, it may be past time to begin investigating the feasibility of these resource sharing agreements.

LESSONS LEARNED ON THE USE OF CBI IN MILITARY TRAINING

Based on the studies reviewed here, some practical advice for the implementation of CBI can be noted. CBI may be best, perhaps most cost-effectively used to provide:

- *Practice.* Training based on CBI has the often noted qualities of patience, privacy, and economy. If large amounts of practice are required to master a subject matter, CBI may be the most feasible and cost-effective way to provide it.

* *Simulation for expensive or inaccessible equipment.* If equipment costing substantially more than desk-top computer systems can be simulated adequately to meet the training objectives at hand, then it is likely that CBI simulations used partially or wholly in place of actual equipment will both lower costs and increase training accessibility. Training using such simulations is both more reproducible (students can try one set of decisions, observe their consequences and try again) and more visible (students can see the invisible in simulations and they can focus on training relevant experience) than is training using actual equipment.
* *Simulation for dangerous or expensive situations.* Experiences that students need in order to achieve training objectives may be too dangerous to provide without simulation. Such experiences are particularly common in military training. Many such experiences can be provided using training technology.
* *Stand-alone materials for physically dispersed learners.* Distance learning frequently focuses on the use of distributing classroom learning using video technology. In many instances, this is an appropriate approach. However, CBI can be provided outside of classroom settings, presented at arbitrary times and places (including barracks, workbenches, and homes), and delivered cheaply.
* *Privacy, closely monitored progress, or both.* Many students in military training—particularly those who pursue full military careers—are highly motivated and would benefit from frequent progress monitoring. Daily, even hourly, monitoring and privacy can be provided by CBI.
* *Standardized, less variable training outcomes.* Because of the assessment that can be built into CBI, its outcomes can be standardized and even certified. This feature has been observed in classroom instruction using CBI where achievement variability is reduced because fewer students are "lost"—students are more likely to reach criterion levels of performance when CBI is used in place of more conventional classroom approaches. Equivalent results for job site training seem likely.

FINAL WORD

On the basis of data and experiences both presented to RSG 16 and available elsewhere, it seems reasonable to conclude that CBI:

* Can be used to accomplish a wide range of instructional objectives across a variety of instructional settings;
* Is often more effective than other more commonly used approaches to military training;
* Is often less costly than other more commonly used approaches to military training; and
* Promises to be more cost-effective than other, more commonly used approaches to military training.

If these conclusions are true, then it is time to take CBI seriously. It should be routinely considered as a standard approach to be used in the design and delivery of military training programs. It should be allocated the necessary initial investment resources and made widely available in military training.

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